Evaluation of Matched Blumlein and Slow-Fast Blumlein Systems for Induction Accelerator Power Systems

W. C. Nunnally

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

May 6, 2002

This report has been reproduced directly from the best available copy.

Available electronically at http://www.doc.gov/bridge

Available for a processing fee to U.S. Department of Energy
And its contractors in paper from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-mail: reports@adonis.osti.gov

Available for the sale to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-mail: orders@ntis.fedworld.gov
Online ordering: http://www.ntis.gov/ordering.htm

OR

Lawrence Livermore National Laboratory
Technical Information Department's Digital Library
http://www.llnl.gov/tid/Library.html

Evaluation of Matched Blumlein and Slow-Fast Blumlein Systems for Induction Accelerator Power Systems.

W. C. Nunnally[a)]

Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94551
USA

Abstract. Two approaches for driving an induction acceleration using a number of stacked Blumlein lines are evaluated and compared. The matched or balanced Blumlein utilizes a single switch and two transmission line sections incorporating identical dielectric materials to drive a beam load. The matched Blumlein line system further requires ferro-magnetic isolation to prevent the accelerating electric field from appearing on the external structure of the system. The Slow-Fast Blumlein line power system utilizes two transmission line sections, with different dielectric materials and two switches, one on each line. The two dielectric materials result in different wave velocities in the respective transmission line sections, thus the slow and fast lines. The Slow-Fast Blumlein system does not require ferro-magnetic isolation since the closure of both switches trap the accelerating electric field within the accelerating structure. This paper discusses two arrangements of dielectrics and conductors to form the Blumlein transmission lines and evaluates and compares the energy density and accelerating performance of these two systems.

INTRODUCTION

The application of stacked Blumlein Lines in powering induction accelerators has been demonstrated since the inception of vector inversion generators. This paper evaluates, quantifies, and compares the performance of the conventional matched Blumlein line approach [1,2] and the "slow-fast" Blumlein approach [3].

BACKGROUND

The conventional, matched Blumlein line or MBLL and the slow-fast SFBLL are illustrated in Fig. 1 a,b and Fig. 2 respectively. The MBLL employs two transmission line (T-line) sections of equal impedance, Z_1, of length, x, and one switch which actives the pulse delivered to the load. The center conductor is charged relative
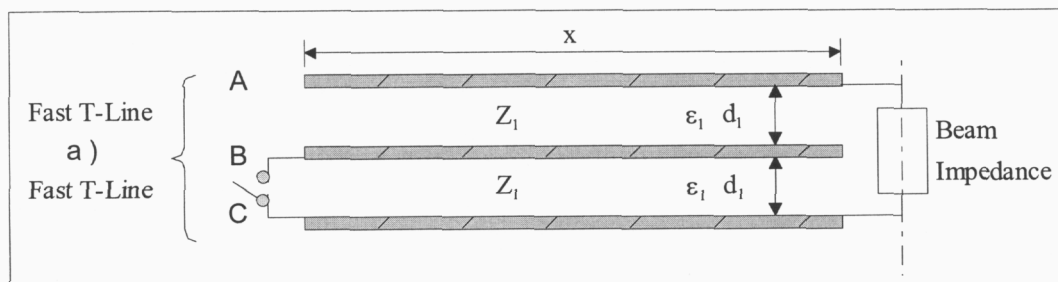

Figure 1a. Illustration of Matched Blumlein Line Geometry

to both the top and bottom conductors such that the initial voltage between conductors

A and C is zero. The closure of the switch between terminals B and C launches a pulse toward the load and simultaneously produces the charge voltage between conductors A and B. In the matched, conventional configuration of Fig. 1, the load voltage is applied across the conductors A and C at the output (right side of figure), but also produces a voltage at the input of the T-lines (left side of Figure). In order to prevent the left side voltage from energizing the outside of the accelerator structure, a ferromagnetic core enclosed by a conductor can be connected to the structure, as illustrated in Fig. 1b, to contain the electric fields and serve as a large isolating
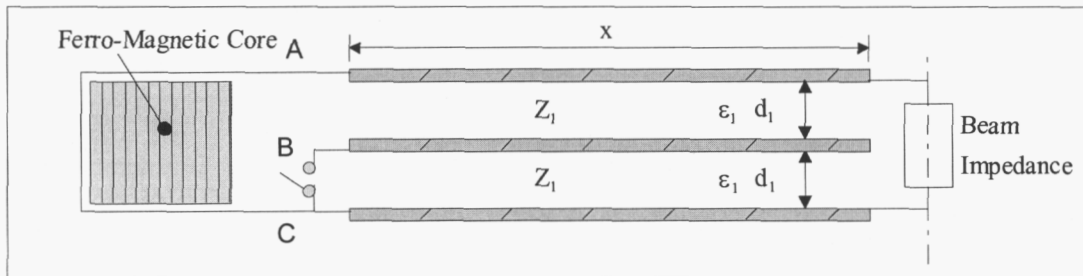

Figure 1b. Ferromagnetic Isolation of rear potential in MBLL

impedance. In Fig. 1 and 2, the load is represented by a beam impedance equal to twice the impedance of an individual transmission line section.

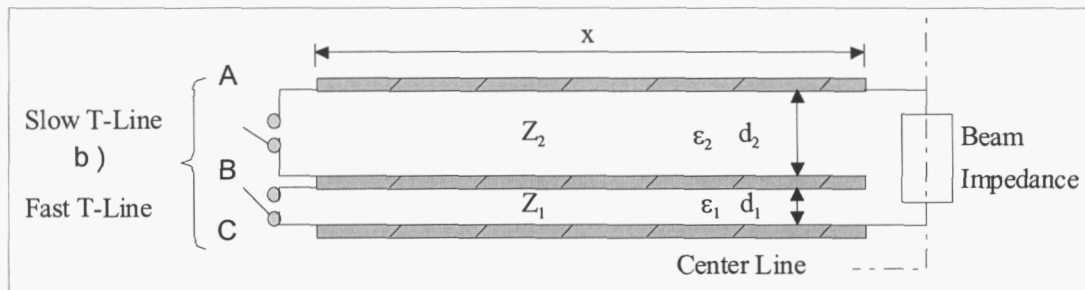The SFBLL system, illustrated in Fig. 2, employs two T-line sections of equal

Figure 2.   Illustration of Slow-Fast Blumlein Line Configuration

impedance, but different wave velocities that result in a slow T-line and a fast T-line, of length x, and two switches.   The different wave velocities are determined by different dielectrics, ε_1 and ε_2, in the slow and fast lines.   In order to make the impedance of the slow line and the fast line equal, the thickness of the dielectric in the slow and fast lines, d_1 and d_2, are adjusted accordingly.   Again, the center conductor is charged with respect to the top and bottom conductors.   Both switches are closed simultaneously.   The load pulse in the SFBLL configuration is initiated when the wave due to the closing of the fast T-line switch reaches the load and terminated when the slow T-line switch wave reaches the load.   The advantage of the SFBLL configuration is that all the electric fields are trapped inside the conductors when the switches are closed and an external electric field does not appear across the accelerator structure. This eliminates the need for the large ferromagnetic cores and thus reduces the weight and volume of the accelerator.

ANALYSIS

Using the above configurations, the impedances of the two lines are matched such that:

$$Z_1 = \sqrt{\frac{\mu_o}{\varepsilon_o \cdot \varepsilon_1}} \cdot \frac{d_1}{w} \quad (1) \quad \text{and} \quad Z_2 = \sqrt{\frac{\mu_o}{\varepsilon_o \cdot \varepsilon_2}} \cdot \frac{d_2}{w} \quad (2)$$

where w is the width of the transmission line sections. Since $Z_1 = Z_2$, the t-line separations are related by:

$$\frac{d_1}{d_2} = \sqrt{\frac{\varepsilon_1}{\varepsilon_2}} \quad (3)$$

The velocity in the individual transmission line sections is determined by the dielectric constant such that the one-way transit times for the two lines are given by

$$T_1 = \frac{x}{c'} = x \cdot \sqrt{\mu_o \cdot \varepsilon_o \cdot \varepsilon_1} \quad (4) \quad \text{and} \quad T_2 = \frac{x}{c'} = x \cdot \sqrt{\mu_o \cdot \varepsilon_o \cdot \varepsilon_2} \quad (5)$$

where c' is the speed of light in the dielectric.

Since the switched wavefronts arrive at the load at different times, the pulse length, T_P, at the load is determined by

$$T_{p-SFBLL} = T_2 - T_1 = x \cdot \sqrt{\mu_o \cdot \varepsilon_o} \cdot \left[\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2} \right] \quad (6)$$

The total energy stored in the two SFBLL lines is a function of the charge voltage, V_C or

$$E_{SFBLL-S} = w \cdot x \cdot \varepsilon_o \cdot V_c^2 \cdot \left[\frac{\varepsilon_1}{d_1} + \frac{\varepsilon_2}{d_2} \right] \quad (7)$$

The energy delivered to the load by the SFBLL is determined by

$$E_{SFBLL-L} = \frac{V_c^2}{Z_B} \cdot T_p = \frac{V_c^2}{Z_B} \cdot \frac{x}{\sqrt{\mu_o \cdot \varepsilon_o}} \cdot \left[\frac{1}{\sqrt{\varepsilon_2}} - \frac{1}{\sqrt{\varepsilon_1}} \right] \quad (8)$$

The energy transfer efficiency for the SFBLL is given by

$$\eta_{SFBLL} = \frac{E_{SFBll-L}}{E_{SFBLL-S}} = 2 \cdot \left[\frac{\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \right] \cdot \left[\frac{\varepsilon_1 - \sqrt{\varepsilon_1 \cdot \varepsilon_2}}{\varepsilon_2 + \sqrt{\varepsilon_1 \cdot \varepsilon_2}} \right] \quad (9)$$

The impedance of the single dielectric Blumlein line or MBLL is equal to that in Eq. (1). The MBLL pulse length is twice the one way transit time of the transmission line section or

$$T_{MBLL} = 2 \cdot x \cdot \sqrt{\mu_o \cdot \varepsilon_o \cdot \varepsilon_1} \quad (10)$$

The MBLL stored energy is given by

$$E_{MBLL-S} = 2 \cdot w \cdot x \cdot \varepsilon_o \cdot V_c^2 \cdot \frac{\varepsilon_1}{d_1}.$$

(11)

and the energy dissipated in the load is given by

$$E_{SFBLL-L} = \frac{V_c^2}{Z_B} \cdot T_p = \frac{V_c^2}{Z_B} \cdot 2 \cdot x \cdot \sqrt{\mu_o \cdot \varepsilon_o \cdot \varepsilon_1}.$$

(12)

So that the efficiency of energy transfer is given by

$$\eta_{MBLL} = \frac{E_{MBLL-L}}{E_{MBLL-S}} = \frac{1}{Z_B} \cdot \frac{d_1}{w} \cdot \sqrt{\frac{\mu_o}{\varepsilon_o \cdot e_1}} = 1$$

(13)

Comparisons of MBLL and SFBLL

The following parameters were calculated to compare the MBLL and the SFBLL accelerator configurations. The matched Blumlein line induction accelerator power configuration is much more efficient in developing load parameters.

TABLE 1. Normalized Parameter Comparison MBLL and SFBLL Accelerator.

Parameter	Normalized MBLL	Normalized SFBLL
Load Electric Field – gradient	1	0.25
Energy Transfer Efficiency	1	0.65
Power Density at load	1	0.06
Pulse length for given length of dielectric	1	0.43

ACKNOWLEDGMENTS

REFERENCES

1.   W. C. Nunnally, Los Alamos National Laboratory Report ", LA-9760-MS, "Accelerator Applications of Photoconductive Power Switches, April 1983.
2.   R. A. Petr, W. C. Nunnally and C. V. Smith, Jr., "Investigation of a Radial Transmission Line Transformer for High Gradient Particle Accelerators," Review of Scientific Instruments, January 1988, pp. 132-136.
3.   G.J. Caporaso,"Induction Linacs and Pulsed Power" in Frontiers of Accelerator Technology, World Scientific 1996.